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# Quarterly Progress Report

*Division 3*

## Radio Physics

15 February 1965

Prepared under Electronic Systems Division Contract AF 19(628)-500 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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# INTRODUCTION

This report summarizes the research and development efforts of Division 3 for the period 1 November 1964 through 31 January 1965. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

J. W. Meyer
Head, Division 3

M. A. Herlin
Associate Head

15 February 1965

Accepted for the Air Force
Stanley J. Wisniewski
Lt Colonel, USAF
Chief, Lincoln Laboratory Office

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# REPORTS BY AUTHORS IN DIVISION 3

15 November 1964 through 15 February 1965

## PUBLISHED REPORTS

### Group Report

| No. | | | | DDC and Hayden No. |
|---|---|---|---|---|
| 1964-65 | Draft Program Description for Radar and Radiometric Lunar Surface Studies | P. B. Sebring, Editor | 20 November 1964 | DDC 609384<br>H-624 |

### Journal Articles*

| JA No. | | | |
|---|---|---|---|
| 2284 | Circular Aperture Synthesis | J. Ruze | Trans. IEEE, PTGAP AP-12, 691 (1964) |
| 2371 | An F-Region Eclipse | J. V. Evans | J. Geophys. Res. 70, 131 (1965) |
| 2434 | On the Behavior of $f_oF_2$ During Solar Eclipses | J. V. Evans | J. Geophys. Res. 70, 733 (1965) |

* * * * *

## UNPUBLISHED REPORTS

### Journal Articles

| JA No. | | | |
|---|---|---|---|
| 2320B | The Kinematics of the Angular Momentum of a Particle. I. Translation Broadening of Angular Momentum | H. E. Moses<br>S. C. Wang | Accepted by Nuovo Cimento |
| 2358A | An Experimental Infrared Radar | E. D. Mills†<br>N. A. Sullivan†<br>J. W. Meyer | Accepted by Microwave J. |
| 2422 | The Measured Transition from Laminar to Turbulent Flow and Subsequent Growth of Turbulent Wakes | W. G. Clay<br>M. Labitt<br>R. E. Slattery | Accepted by AIAA J. |
| 2479 | The Cause of the Midlatitude Evening Increase in $f_oF_2$ | J. V. Evans | Accepted by J. Geophys. Res. |

* Reprints available.

† Author not at Lincoln Laboratory.

## Meeting Speeches*

| MS No. | | | |
|---|---|---|---|
| 1202 | Measurements of Electrical Fluctuations in Wakes in Hypervelocity Pellets, Using Langmuir Probes | R. E. Richardson<br>J. Herrmann<br>R. S. Cooper† | AMRAC, Chicago, Illinois, 16-18 November 1964 |
| 1207 | The Mechanics of the Quantum-Laser and Maser | J. W. Meyer | ASME, Waltham, Massachusetts, 19 November 1964 |
| 1239 | On the Interpretation of Radar Reflections from the Moon | J. V. Evans | Subcommittee of Physics in Space, San Juan, Puerto Rico, 7-8 December 1964 |
| 1244 | Radar Studies of the Moon | J. V. Evans | IEEE, Boston, Massachusetts, 7 January 1965 |

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

† Author not at Lincoln Laboratory.

# ORGANIZATION

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## GROUP 31

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# SURVEILLANCE TECHNIQUES
# GROUP 31

Group 31 operates and maintains the Millstone radar complex and the Haystack Experimental Facility at the Laboratory's Millstone Hill Field Station. The Group also conducts a program of radio physics, astronomy, and space surveillance research using these facilities.

During this quarter, Haystack reached a stage of completion which has permitted radiometric observations for the primary purpose of antenna system and radome evaluation. At Millstone, activities have concentrated on space surveillance and the installation and checkout of new hardware.

## I. SPACE SURVEILLANCE

### A. Observational Program

The schedule for the Millstone tracking program in support of the Air Force Space Detection and Tracking System (SPADATS) has been increased to one full day per week from the former one-half day schedule. In these operations, emphasis is placed on tracking objects which, for one reason or another, require a radar of Millstone's sensitivity and are not frequently tracked by other sensors. During this period, 18 such objects were tracked (many of them more than once) and data were passed to Space Track.

Operations of a special nature involved the IMP-1 satellite tracked on 10 November. By tracking this satellite several times, Millstone assisted NASA in maintaining the orbit during a period when transmission failed after the satellite entered the earth's shadow.

A number of observations of the West Ford belt were made. At L-band, the Millstone radar obtained returns from stray clumps of the X-band dipoles. No returns were observed in the region of the belt proper, but about 60 targets ranging in cross section from 6 to 200 $cm^2$ were detected at heights from 950 to 1800 nm.

### B. Sensor Improvement Program

Tests have been under way this quarter with two new modes of the MITRE-Millstone interferometer operation – a staggered pulse-repetition rate and a 1000:1 pulse compression. The first has been successfully demonstrated to remove ambiguities in the fine Doppler measurements; the second has shown a range resolution of 500 feet.

Work on the digital monopulse has continued. It is anticipated that this equipment will be fully operational during the next quarter.

Specifications have been written for a version of the Electronic Systems Precision Orbit Determination (ESPOD) program that could be used on the SDS-9300 computer at Millstone. Among other functions, this program would work in real time to assist satellite tracking by performing a best-fit to existing data in order to extrapolate future positions.

## II. RADIO AND RADAR ASTRONOMY

### A. Planning

A Haystack scheduling committee, established in Group 31, has outlined a proposed schedule for use of the Haystack antenna in 1965. The schedule includes experimental programs in three major areas: space communications, radio astronomy (radiometric measurements), and radar astronomy. Cooperative use of Haystack by radio astronomers from M.I.T. and Harvard is included in the planning.

If Haystack is to be used to make the planetary radar measurements required for the "Fourth Test of General Relativity," which has been proposed by Dr. Irwin Shapiro, then the system sensitivity must be considerably improved. A proposal for upgrading the CW radar capability by 10 db has been prepared. Its salient features include increasing the transmitter power output to approximately 500-kw CW and achieving a system temperature of 75°K by using improved parametric amplifiers or masers.

### B. Planetary Radar Studies

Analyses of the 1964 Venus and Mercury observations are now complete, and a paper summarizing the results has been prepared. Observations of Venus were successfully made on 46 days during the period 21 February to 7 October 1964 and of Mercury on 5 days during the period 29 April to 4 May 1964. The range of Venus was determined to an accuracy of ±75 km at the beginning and end of the period and to ±1.5 km during the two-month period centered on close approach. A final tabulation of the flight-time and Doppler determinations referred to 1200 UT on each day has been compiled. The flight-time determinations have been corrected for (1) all receiver delays, and (2) the effective depth of the target (i.e., the distance between the leading edge of Venus and the point somewhat more distant that corresponds to the peak of the echo.

The surface of Venus is somewhat smoother than that of the moon in two respects. Radar observations of the moon at 68 cm indicate that 20 percent of the power is reflected by small-scale rough structure on the surface. This suggests that about 10 percent of the surface is covered with structure comparable in both horizontal and vertical dimensions to the wavelength. For Venus, the corresponding figure appears to be about 5 percent. The remainder of the power is reflected from the larger-scale undulations on the surface.

The radar cross section of Venus was determined after allowance for the fact that our pulses do not illuminate the whole surface at any instant – this proved to be 15 percent of the projected area $\pi a^2$. The corresponding value for the moon is half as much. This leads to the conclusion that the dielectric constant of the material forming the surface of Venus (assuming that it is nonmagnetic and of low conductivity) is about 5. The corresponding value for the moon is 2.7 implying that, by contrast, lunar rocks must be broken, or porous, with a packing factor comparable to sand (40 percent).

### C. Radiometric Work

The radiometer box has been operated on Haystack since 14 December. Observations were confined to nights and weekends and averaged about 30 hours per week. The objective of these observations was the radiometric evaluation of the Haystack system. The principal areas of

this evaluation were determination of the antenna efficiency, calibration of the antenna pointing, and investigations of radome effects on system performance. Although the evaluation was not completed during this reporting period, preliminary results are available at the two radiometric frequencies, 8 and 15.5 Gcps, and are summarized below.

| | Frequencies | |
|---|---|---|
| | 8 Gcps | 15.5 Gcps |
| Antenna efficiency (over-all)* | 30 ± 6 percent | 15 ± 5 percent |
| Inferred efficiency, antenna alone | ~50 percent | ~25 percent |
| Background antenna temperature | | |
| Elevation angle 90° | 24 ± 4°K | 34 ± 4°K |
| Elevation angle 30° | 37 ± 4°K | 45 ± 4°K |

The lower value of efficiency at 15.5 Gcps suggests surface tolerance of about 0.060 inch. Hence, errors in the initial rigging of the antenna surface appear to be larger than expected. The background antenna temperatures include contributions due to the scattering of thermal emission from the ground into the antenna by the space frame of the radome. (The atmosphere alone contributes about 4°K at 8 Gcps looking toward the zenith and, similarly, about 8°K at 15.5 Gcps.)

No clearly detrimental radome effects have been found in connection with differential shifts in pointing or fluctuations in background temperature with changes in antenna azimuth.

The data on pointing errors that were obtained on radio sources appear to be quite consistent and reproducible. With very preliminary values for the pointing corrections, Haystack can now be pointed to within about 0.020°, provided that the presently existing servo errors are subtracted out (see Sec. IV).

Preliminary observations of the moon and several of the bright radio sources have given very promising results.

## III. IONOSPHERIC STUDIES

Throughout 1963, backscatter observations were made approximately every week for a 30-hour period. This work was analyzed during 1964, and the results are summarized in Ref. 1. Other papers,[2-5] which cover particular aspects of the results, have been published or accepted for publication. The 1964 measurements were also made for 30-hour periods, but were made every two weeks. Greater attention was given this time to the processing of the weakest signal spectrums (from which the electron and ion temperatures are derived) corresponding to greatest heights. This was accomplished by recording about half the data and processing it later, i.e., between runs. Since the total time required to observe the height variation of density, electron and ion temperatures has remained one hour, steps are now being taken to reduce this time to one-half hour. Thus, during 1965 the measurements will be taken so that the height variation of the three measured quantities can be obtained at half-hour intervals. This requires that we rely to a greater extent on later processing of recorded data. Accordingly, we plan to

* These figures include an estimated radome loss of 1.2 db at 8 Gcps and 1.6 db at 15.5 Gcps, and microwave system losses.

operate the equipment for 48-hour intervals once per month. These will be chosen to include the Quarterly and Priority World Days of the IQSY (International Year of the Quiet Sun).

## IV. STATION EQUIPMENT AND IMPROVEMENTS

### A. Haystack

#### 1. General

Attempts to shift emphasis at Haystack from testing to operation were only partially successful during this quarterly period. Reliable antenna operation under control of the pointing computer was limited to short-time intervals because of problems in the control and drive system. Demonstrations of the inherent capability of the digital servo to provide precision pointing at low angular rates and under computer control were successful. During December, the Air Force accepted the antenna from the contractor (North American Aviation) and gave the task of operating the facility to Lincoln Laboratory. Progress in the integration-test program of the radar/communications (R/C) box was also slow. Initial tests of the R/C box on the antenna are now scheduled for February 1965.

#### 2. Antenna System

Preliminary RF evaluation and calibration of the 120-foot antenna and radome gave the results described in Sec. II-C. In all these operations, the complete radiometric system, data processing equipment, and the real-time computer programs have been extremely effective and reliable.

In early November, initial closed-loop tests of the digital servo were made in manual mode, later tests were under control of the Univac 490 computer. Precision pointing to accuracies of 0.005° at static and sidereal angular rates was demonstrated for brief periods. Behavior of the servo control and drive system was less than desirable because of intermittent equipment problems.

#### 3. Radiometer Box

Early in December, and after a month of refitting and new installation, the radiometer box was hoisted onto the mount for the second time. Modifications included (a) provision of polarization control at 8 and 15.5 Gcps; (b) provision for simultaneous operation at 8 and 15.5 Gcps; (c) refitting of air conditioning, and (d) absolute calibration of the noise temperature system with a liquid nitrogen source.

#### 4. Radar/Communications Box

Checkout of the R/C box on the test dock continued. The first VA-879 kylstron was operated at the 80-kw CW level. Because this tube developed a crack in the output waveguide window, a 25-kw VA-849 klystron has been substituted, and checkout of the box is continuing. The usual turn-on and interfacing problems have been encountered and are being corrected. The R/C box will be placed on the antenna in February.

All support equipment required for operation of the cooled parametric amplifiers has been installed and checked out in the R/C box. Included are a system temperature monitor, a

ferrite-switched radiometer front end, pump and leveling equipment, and crystal current monitors. The parametric amplifiers have operated satisfactorily at room temperature. Reliable operation with either liquid nitrogen or liquid helium cooling has not been achieved.

Arrangements have been made with the Rome Air Development Center to obtain the loan of a high-voltage series beam switch and regulator for use at Haystack through the fall of 1965. This unit is currently being assembled by Energy Systems, Inc.

5. Control Room Electronics

Most of the control room equipment is integrated with either the radiometer box or R/C box. Intersite couplings that provide digital data transfers to and from Millstone were tested. Successful operations were conducted using the Univac 490 computer program to steer the Millstone radar tracking antenna onto satellite targets. Similar and more extensive tests were conducted using the Univac 490 computer to point the 60-foot communications antenna. Installations and integration work are progressing on several pieces of equipment including modified A/D converters on the R/C receiver channels, automatic offset frequency steering equipment for Doppler corrections of lunar and planetary experiments, a 2-msec sequential Doppler processing (SDP) system to provide detection and frequency measurements in pulsed radar operation, a SCAMP monopulse system for determining tracking errors in angle, and computer output display equipment.

6. Facilities

The heating facilities for the 150-foot space-frame radome were completed, checked out, and are in operation. At present, the radome temperature is held constant at 60°F at the base of the tower. Air circulation equipment to provide control of the temperature environment of the antenna is not complete.

7. Antenna Test Van

A van-type truck, containing transmitters at L-band (1.295 Gcps) and X-band (7.75 Gcps) and radio communications equipment, was instrumented, tested, and positioned on Pack Monadnock mountain to be used for Millstone and Haystack field pattern measurements. It has been operated with the Haystack antenna at X-band.

## B. Millstone

The L-band radar was inoperable for six weeks in late November and December. During this time, a new waveguide was installed in the antenna tower. One week prior to the scheduled downtime the slip rings carrying power to the antenna drive motors short-circuited and were seriously damaged. The slip-ring assembly has been returned to the manufacturer for repair and is expected to be completed about the first of March. In the meantime, the antenna is being operated in a temporary cable-wrap arrangement.

During this reporting period, a great deal of hardware installation and construction took place at Millstone. The most significant accomplishments were:

(1) Integration of two new AstroData master timing generators into the Millstone system.

(2) Checkout of the digital portion of the digital monopulse.

(3) Installation and operation of the intersite coupling system between the Millstone radar and the Haystack computer. The Univac 490 has directed the Millstone antenna and, upon completion of programs and interfaces, will be able to control the radar and process some types of radar data.

Initial planning on a number of new computer programs for the Millstone radar was undertaken during the past quarter. Some of these programs are (1) coherent integration for satellite detection, (2) coherent integration in real time of planetary echoes, and (3) incoherent integration of planetary echoes. All these programs are to be implemented on the SDS-9300 computer.

## V. SOLAR RADAR STUDIES

The El Campo radar is no longer operated by the Laboratory. A draft of a technical report which summarizes the results obtained during three years of operation of the El Campo solar radar site is nearly complete.

Several models of the extended corona consistent with the solar radar data, radio astronomy measurements, and space probe results have been studied in order to compute the effects of refraction, group delay, and scintillation on an X-band transmission path passing near the sun. These effects may be significant in the proposed measurements of the relativistic effect of solar gravity on paths adjacent to the sun, utilizing radar echoes from Mercury and Venus.

## VI. PROPAGATION STUDIES

### A. Atmospheric Backscatter

Further observations of radar returns at 75, 10, and 3 cm were made at Wallops Island, Virginia during November in collaboration with the weather-radar research group of the Air Force Cambridge Research Laboratories. These observations were accompanied by aircraft measurements and other meteorological data in the general vicinity of the regions of the radar returns. These combined data have provided strong evidence of stratified returns from apparently clear atmosphere with a unique frequency dependence in contrast to the frequency dependence associated with "angels" and other discrete objects such as birds and insects.

### B. Rainfall Attenuation Studies

The final results of a statistical study of 1961 to 1963 weather radar data was completed by Dr. Pauline Austin and co-workers at the M.I.T. Meteorology Department under a contract supported by Division 6. An analysis of these results, as applied to some simple spatial models of space communications paths and to only selected severe attenuation conditions, has indicated the probable utility of further enlargement of similar statistical studies for a wider range of rainfall rates. A proposal for an enlarged study was prepared by Dr. Austin and was recommended for consideration for continuing support by Division 6.

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2. J. V. Evans, "Ionospheric Temperatures During the Launch of NASA Rocket 8.14 on July 2, 1963," J. Geophys. Res. 69, 1436 (1964).

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4. J. V. Evans, "An F-Region Eclipse," J. Geophys. Res. 70, 131 (1965).

5. J. V. Evans, "The Cause of the Midlatitude Evening Increase in $f_oF_2$," J. Geophys. Res. 70 (1965) (in press).

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13. ABSTRACT

Group 31, Surveillance Techniques, operates and maintains the Millstone radar complex and the Haystack Experimental Facility at Lincoln Laboratory's Millstone Hill Field Station. The Group also conducts a program of radio physics, astronomy, and space surveillance research using these facilities.

During this quarter, Haystack reached a stage of completion which has permitted radiometric observations for the primary purpose of antenna system and radome evaluation. At Millstone, activities have concentrated on space surveillance and the installation and checkout of new hardware.

14. KEY WORDS

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